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NAVIGATION PERFORMANCE USING PARALLAX RANGE LIGHTS

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16. Abstract

At the present time, the U.S. Coast Guard employs a two-station or parallax range method for indicating to a vessel's operator the correct path to follow while proceeding along certain navigation channels. Vertical alignment of two lights, one more distant than the other, indicates that the vessel is positioned on the range axis, and any deviation from this course is readily apparent. In order to compare the sensitivity of various methods for range displays, including presumably less expensive single-station ranges, the performance of observers on four parallax range configurations was assessed psychophysically by measuring the observers' ability to determine lateral position in a channel and direction of motion across a channel.

It was found that the currently used two-point fixed range light configuration affords a high degree of sensitivity in determining lateral position and motion. With a two-point flashing range, sensitivity is slightly decreased and errors in judging direction of motion are significantly higher than with the fixed range lights. Two alternative parallax range light configurations afforded a slight potential improvement in sensitivity over the two-point fixed range lights. Strong evidence was found that training or experience could improve performance regardless of range light configuration. Judgments of motion toward the range axis were signficantly more sensitive than judgments of motion away. These findings describe the sensitivity afforded by present parallax ranges and will allow comparison of proposed single-station ranges with present configurations, to evaluate their adequacy as aids to navigation.

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METRIC CONVERSION FACTORS

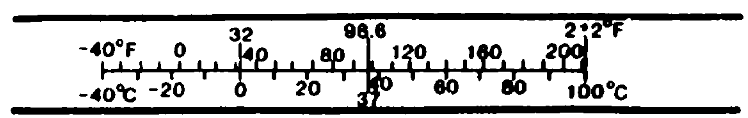
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286. Units of Weights and Measures. Price $2.25. SD Catalog No. C13 10 286

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



SUMMARY PAGE

THE PROBLEM

To determine the navigation performance of observers using current and alternative parallax (two-station) range lights, to serve as a baseline for subsequent comparison with single-station ranges proposed by the U. S. Coast Guard.

FINDINGS

The ability of observers to detect deviation from range axis and motion acrosu range axis was determined for four types of parallax range light configurations. Onu type of range light configuration in current use was associated with substantial errors and reduced motion discrimination, while two alternative configurations yielded better performance than current configurations.

APPLICATION

These findings describe the sensitivity afforded by current range light configurations and will allow comparison of proposed single-station range lights with present configurations, to evaluate their adequacy as aids to navigation.

ADMINISTRATIVE INFORMATION

This study was conducted at the Naval Submarine Medical Research Laboratory under Contract No. MIPR Z51100-9-0002 with the U. S. Coast Guard Research and Development Center, Groton, CT. The manuscript was submitted for review on 29 September, approved for publication on 15 November 1989, and has been designated as NSMRL Report No. 1149.

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NAVIGATION PERFORMANCE USING PARALLAX RANGE LIGHTS

At the present time, the U.S. Coast Guard employs a visual method for indicating to a vessel's operator the correct track or "range" to follow while proceeding along certain navigation channels, such as approaches to harbors and within rivers. This is the parallax range indication, which for nighttime use consists of a pair of lights in fixed positions, with the farther light slightly higher than the nearer one (Figure 1). Vertical alignment of the lights indicates that the vessel is positioned on the range's longitudinal centerline, or range axis, and any deviation from this course is readily apparent.

Although effective and easy to use, such aids to navigation are expensive, since the rear range light is typically located on shore, requiring the purchase, construction, and maintenance of this site. The Coast Guard is therefore seeking alternatives for providing this same range information using a single-station range indicator, that is, a device located at one site.

The first step in comparing range displays is to measure baseline performance afforded by the present parallax system. This is required for subsequent evaluation of proposed single-station ranges. The study described here measured performance in a dynamic situation on two typical range displays and two possible alternatives, and, in addition, performance on two of these range displays in static situations. In the dynamic simulations, we measured the observers' ability to judge whether they were moving toward or away from the range axis. Sensitivity to this motion was measured at different distances from the range axis to examine the effect across the width of the channel. In the static simulations, we measured the observers' sensitivity to judge whether they were on or off the range axis. The simulations were conducted on a computer-driven high resolution CRT.

Method

Observers

Thirteen observers, 11 men and 2 women, participated in the dynamic experiments. Their ages ranged from 23 to 59 years, with a median of 34.3 years. All had 20/25 or better visual acuity, with correction if required. Eight of these had extensive experience as psychophysical observers, four of whom also participated in the static simulations. The remaining five persons had virtually no experience as psychophysical observers.

Apparatus

The range configurations were simulated on a Ramtek 9400 high resolution (1024 x 1280 pixels) color display system. This was

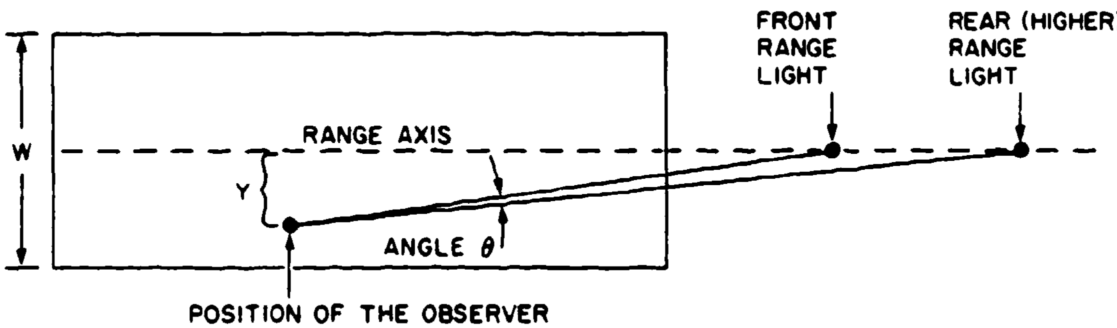

Figure 1. Top view of a parallax range. W: channel width; Y: distance of observer from range axis; θ: horizontal component of the angle between the lights.

driven by a DEC VAX-11/730 computer equipped with a Laboratory Peripheral Accelerator for real time measurement and control. Observers responded by means of an auxiliary key pad.

Displays

Four types of parallax range indicator lights were simulated dynamically. The first two types listed below are in current use. The latter two types have been proposed as possible alternatives.

- Two-point fixed. This range display consisted of two lights which were always on and which were vertically aligned when viewed from the center of the channel. This was simulated as a pair of lights 0.6 arc min in diameter, separated by 4.0 arc min when aligned (Figure 2A). When viewed from off axis, the two lights were not vertically aligned and the misalignment increased with increasing distance from the center of the channel.

- Two-point flashing. A second display was similar to the above except that the two lights were flashed. The upper light exhibited an Equal Interval 6.0 flash characteristic (3.0 sec on and 3.0 sec off), while the lower light showed a Quick Flash characteristic of 0.3 sec on and 0.7 sec off (Figure 2B).

- Extended source. A third display consisted of two bars of light, 0.3 arc min x 6.0 arc min, oriented vertically with no separation between them (Figure 2C). As with the spots of light, they were in vertical alignment only when seen from the center of the channel. They were always on.

- Path indicator. The fourth type of parallax range indicator consisted of a column of lights (Figure 2D). The center light, larger than others, was in alignment with the column only when viewed from the center of the channel. This type of display is typically used as a glide slope indicator for landing on aircraft carriers. In that case it is oriented horizontally to aid pilots in judging elevation. In the present experiment, the device was oriented vertically so that lateral position rather than elevation was indicated. The device used on aircraft carriers does not provide continuous information on elevation, but rather shows five discrete elevations. This device was simulated to provide a continuous change in lateral position to determine if this enhanced display improved performance.

For the static experiments, only the two-point and extended source ranges were simulated.

Procedure

Observers were seated in a dark ro 5 meters from the

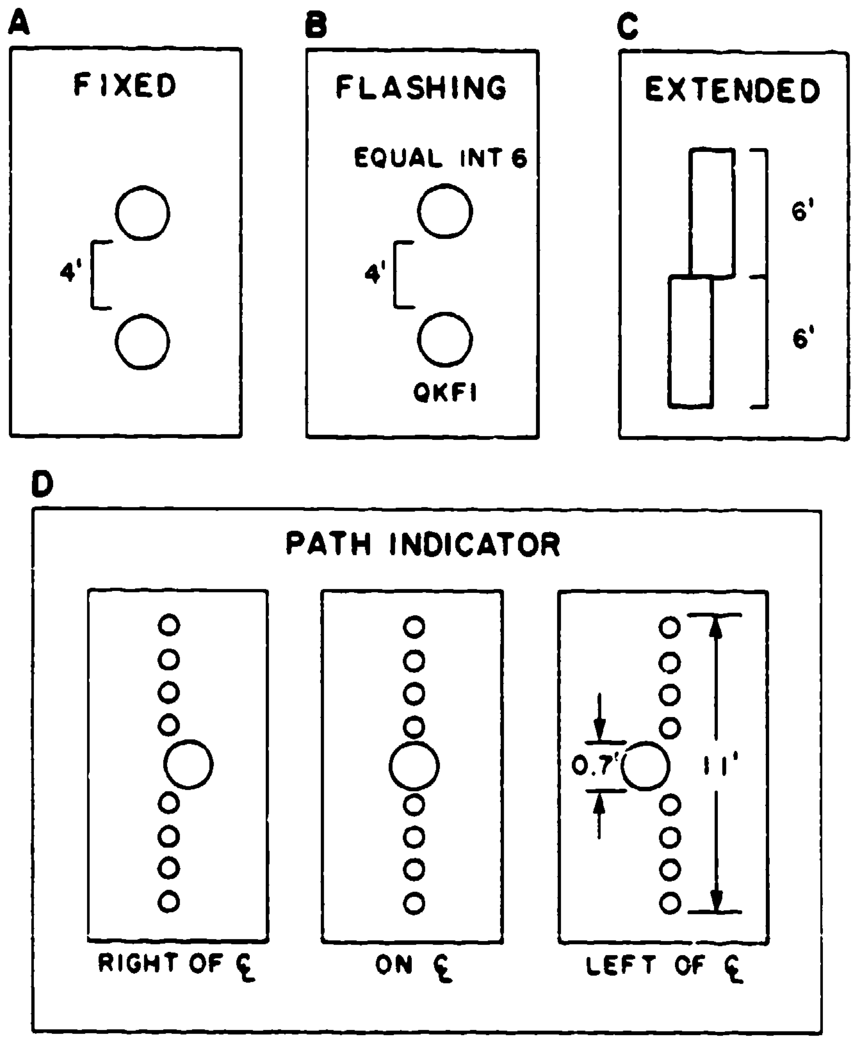

Figure 2. Four parallax range light configurations.

display monitor. The monitor screen subtended visual angles of 2.4° high x 3.3° wide and was uniformly illuminated to 0.003 cd/m^2, equivalent to the night sky with a partial moon. The stimuli were centered on the screen, white in color, and had a luminance of 100 cd/m^2. Observers dark adapted for 5 min before beginning data collection.

Dynamic Simulations. For each experiment, one of the four types of parallax range indicators was displayed on the monitor in a configuration that corresponded to the view of that range from some distance off the range axis. As soon as the observer could correctly judge the right-left direction of motion, he/she pressed a button corresponding to the direction of motion. If the correct button was pressed, the computer recorded the difference between the start position and the position when the button was pressed. Then, after a 2-sec intertrial interval, the next trial began. If an incorrect response was made, the computer terminal beeped to provide feedback to the observer, the error was recorded, and that trial was presented again later in the experimental session.

Figure 3 shows an example of this procedure for a two-point range. The range was displayed (Figure 3A), and after a variable foreperiod (1 - 5 sec), the bottom light began to move slowly to the left (Figure 3B). When the correct button was pressed (Figure 3C) the distance traversed by the lower light was recorded by the computer.

The lower light (middle light in the case of the path indicator) moved at 9.3 arc sec (1 pixel) per second. Observers could not actually see the movement in the range as it moved slowly, like the minute hand on a clock. Judgments were based on the position of the range at some time after the start of the motion. Some observers reported making the judgments on the basis of change of verticality of an imaginary line between the two lights in the two-point range configurations.

The 9.3 arc sec/sec rate of lateral motion was chosen because of hardware and software considerations. The actual rate of movement of a vessel that corresponds to a change of 9.3 arc sec/sec depends on the lateral sensitivity of the range, or K factor, described as a rough measure of the fraction of the channel width that one must laterally depart from the range axis to make it apparent that the two range lights are out of vertical alignment. Lateral sensitivity, K, is defined by the equation:

$$K = (\theta/\Delta)(Y/W)$$

where θ is the horizontal angular separation between the two range lights, Δ is the vertical angular separation, Y is the lateral difference of the observer from the range axis, and W is the width of the range or navigation channel (see Figure 1)

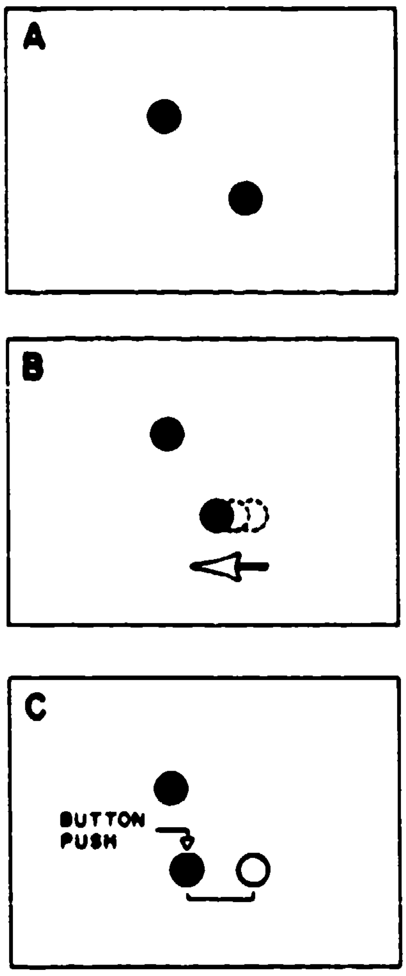

Figure 3. Experimental procedure for motion threshold (dynamic) experiments. A: Start position; B: lower light in motion; C: position when observer detects that lower light has moved. The angular distance moved is recorded by computer.

(Commandant, U.S. Coast Guard, 1980). For range sensitivities of K varying between 1.0 and 4.5, the corresponding cross-track velocities vary between 11.[illegible] and 2.6 knots.

The 11 starting positions, as defined by the position of the lower light (middle light in the case of the path indicator) relative to the range axis, were 1.2, 2.5, 3.7, 4.9, and 6.2 arc min left and right of range axis, plus the 0.0 position of vertical alignment. Performance on each range configuration was measured in a single experimental session, which consisted of one trial at each starting position presented in random order in both left and right directions of motion, repeated over three blocks. The session thus comprised 66 trials, and lasted about 50 min. Observers were given 42 practice trials prior to data collection.

Static Simulations. These experiments were similar to those conducted by Westheimer and McKee (1977). In separate experiments, either the two-point or the extended source range was presented with the lower light in one of nine positions, 9.3, 18.6, 27.8, and 37.1 arc sec to the left and right of range axis or vertically aligned (on the range axis). The observer was presented, in random order, one of the nine configurations once every 4 sec for 0.2 sec. The observer was required to press one of two buttons on the keypad depending on whether the lower light was to the left or to the right of the range axis, with either response being correct for the on-axis position. Each position was presented randomly 30 times in a 270-trial session which lasted 18 min. The computer recorded each response and signalled the observer of errors via a terminal beep. Each observer served in two sessions for both the two-point and extended source range configurations for a total of 540 trials per configuration.

Results

Dynamic Simulations

A repeated measures analysis of variance (ANOVA) was computed on the deviations from start position for the following factors: 4 Range Indicator Configurations x 2 Directions of Motion (to the right or left) x 11 Start Positions x 13 Subjects. The interaction of direction of motion with start position defines the direction of relative motion effect (DRM, toward or away from range axis). This ANOVA is presented in Table 1, with results illustrated in Figure 4, showing the average thresholds for detecting a deviation both left and right of start position for the four types of parallax ranges. Threshold is the average deviation from start position required by the observers to correctly judge the direction of motion for that range. Higher thresholds correspond to poorer performance.

As given in Table 1, thresholds vary significantly with range configuration. Thresholds are 0.2 arc min higher for the two-point fixed range than for the extended source range. With the

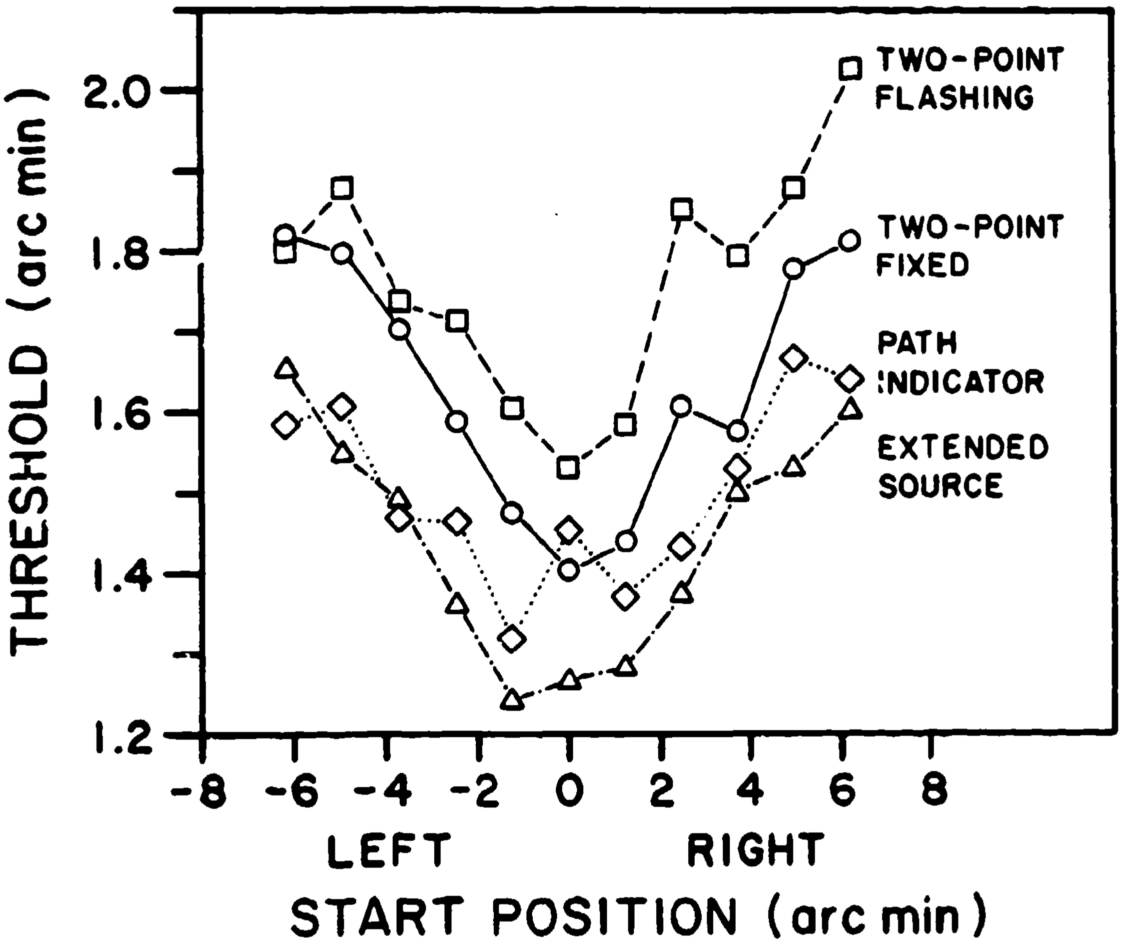

Figure 4. Motion thresholds for four parallax range light configurations.

two-point flashing range, mean thresholds increase by an additional 0.13 arc min. A Newman-Keuls test showed a significant difference between only the extended source and the two-point flashing range configurations ($p < .05$).

Table 1

Summary of ANOVA on Deviation Thresholds for Parallax Ranges

Source	df	F	Probability
Range Configuration (A)	3,36	3.46	$p < .05$
Direction of Motion (B)	1,12	2.25	--
Start Position (C)	10,120	8.23	$p < .001$
Direction of Relative Motion (B x C)	10,120	15.36	$p < .001$
Range Configuration x DRM (A x B x C)	30,360	2.93	$p < .001$

The effect of start position was also significant. Thresholds are smallest for start positions at or near the range axis (start position of 0.0) and increase as the start position distance increases left or right from center. This means that observers can easily determine whether they are moving toward or away from the range axis when near the axis, but they require a greater change in lateral position to correctly judge their direction of motion when off the range axis.

From Figure 4 it appears that range configuration may tend to have an effect on the variation in thresholds with start position. Thresholds for the path indicator are not affected by start position as much as the other three parallax ranges. Mean thresholds for the path indicator vary from 1.45 arc min at start position 0.0 to 1.61 arc min at the extreme start position, a difference of 0.16 arc min. The other three range configurations show differences of about 0.40 arc min between a 0.0 arc min start position and the extreme start positions. This Range Configuration x Start Position interaction was not significant, however.

The DRM effect, the significant interaction of direction of motion with start position, indicates that thresholds for judging motion toward the range axis are different from thresholds for motion away from the range axis, and this effect varies with range configuration. Figures 5 - 8 show these results for each range configuration. Observers were better at judging changes when the direction of relative motion was toward the range axis than when it was away. This difference was greatest for the path indicator, and least for the two-point flashing configuration, which had the highest overall thresholds.

Separate ANOVAs were computed on the thresholds for each range configuration. These showed that start position had a significant effect on thresholds in all four range configurations,

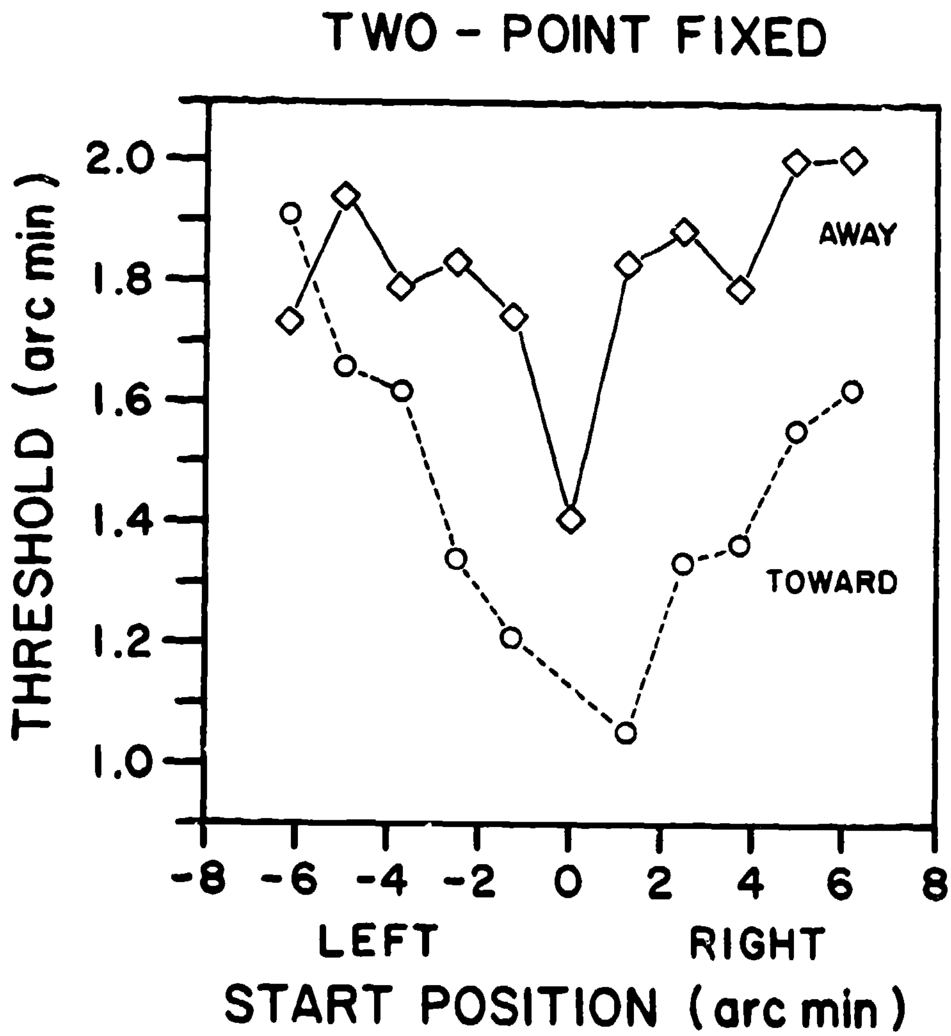

Figure 5. Thresholds for relative motion toward and away from the range axis for the two-point fixed range.

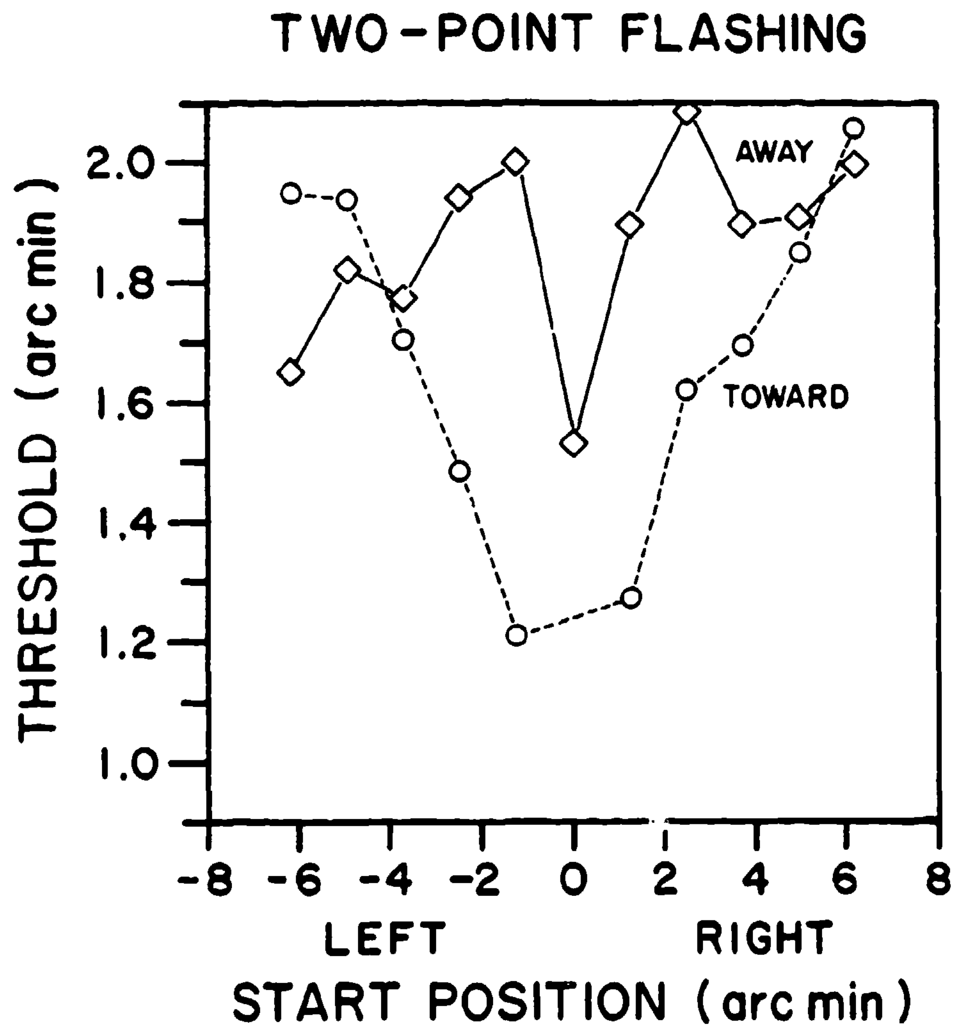

Figure 6. Thresholds for relative motion toward and away from the range axis for the two-point flashing range.

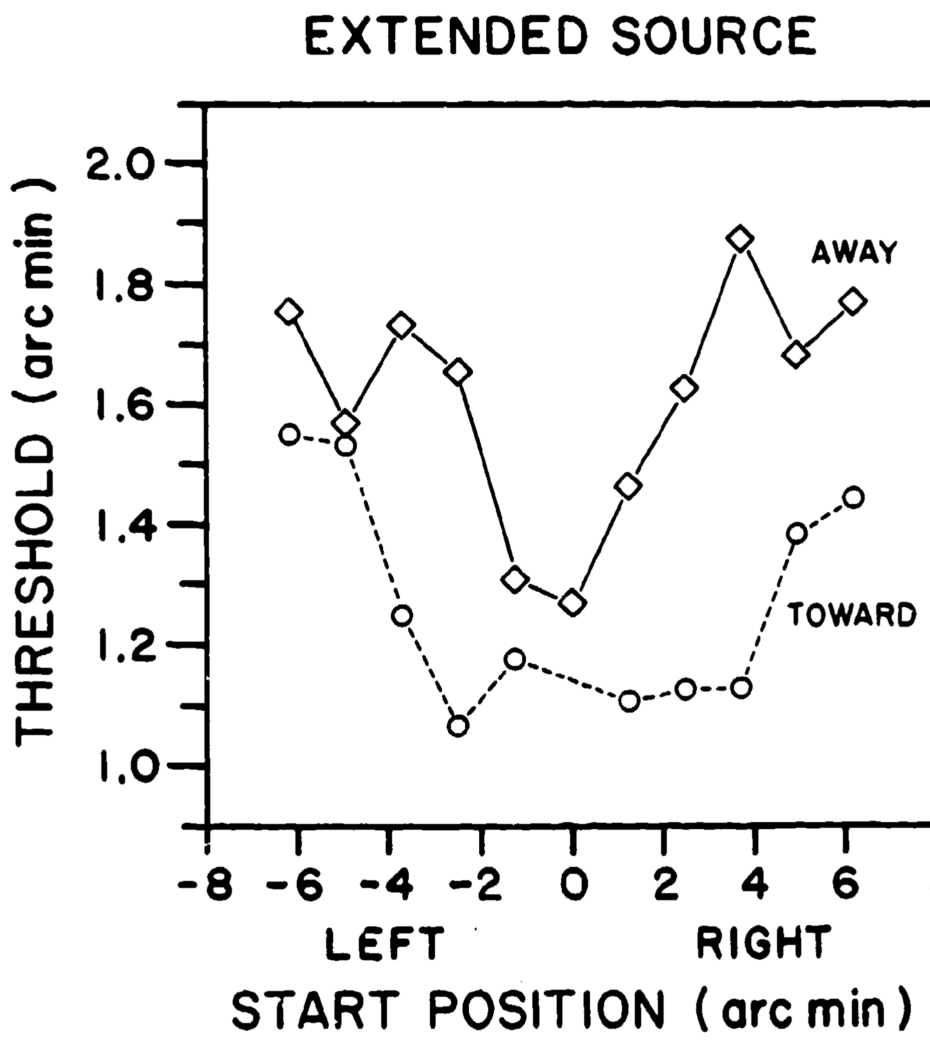

Figure 7. Thresholds for relative motion toward and away from the range axis for the extended source range.

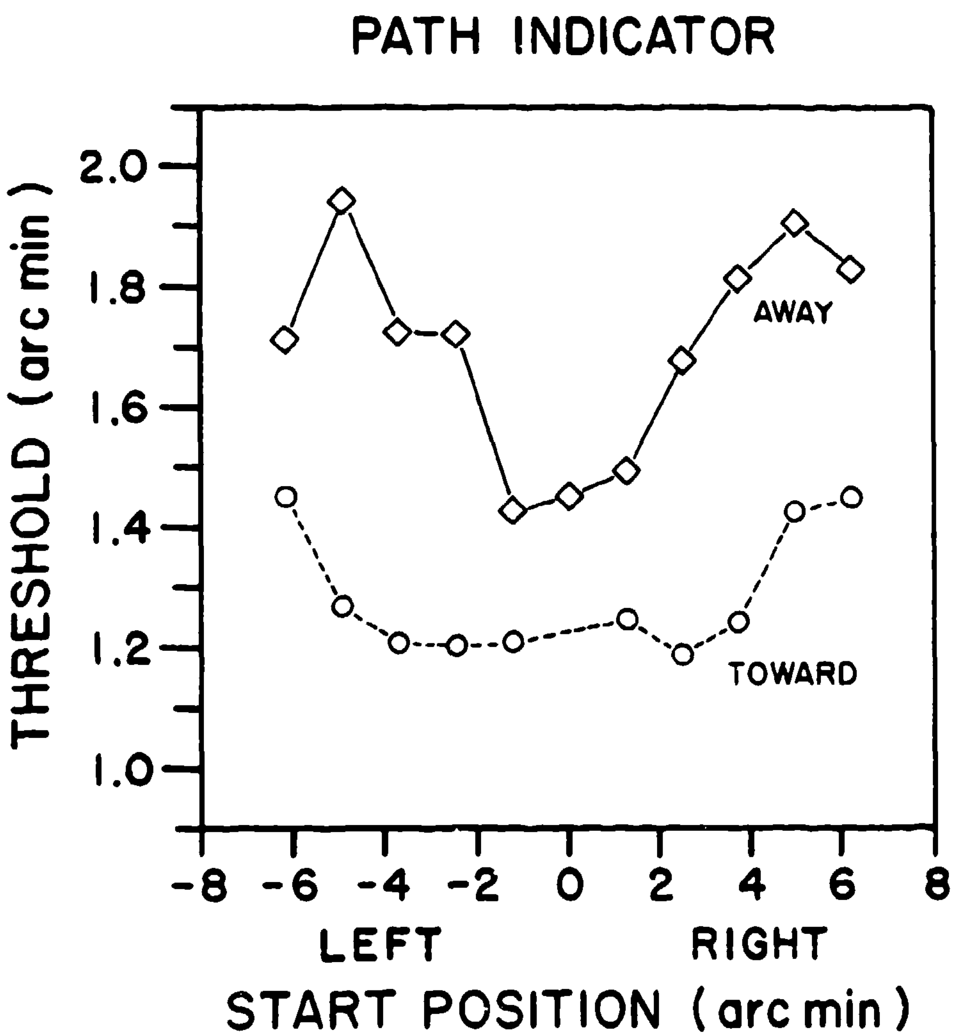

Figure 8. Thresholds for relative motion toward and away from the range axis for the path indicator range.

as shown in Table 2. Furthermore, thresholds for motion toward the range axis were significantly different from motion away from the range axis, as shown in Table 3.

Table 2

ANOVA for Start Position

Range Configuration	df	F	Probability
Two-point fixed	10,120	4.43	$p < .001$
Two-point flashing	10,120	3.45	$p < .001$
Extended source	10,120	4.83	$p < .001$
Path Indicator	10,120	2.03	$p < .05$

Table 3

ANOVA for Motion Toward and Away from Range Axis (DRM)

Range Configuration	df	F	Probability
Two-point fixed	10,120	7.71	$p < .001$
Two-point flashing	10,120	7.37	$p < .001$
Extended source	10,120	7.36	$p < .001$
Path Indicator	10,120	10.04	$p < .001$

Table 4

Mean Error Percentages by Range Configuration

	Direction of Relative Motion		
Range Configuration	Toward	Away	Mean
Two-point fixed	9.5	12.4	11.1
Two-point flashing	17.1	18.0	17.5*
Extended source	6.7	10.3	8.6
Path indicator**	4.4	13.3	9.2
All			11.6

*Significantly different from all others, which were not significantly different from each other. **Direction of Relative Motion effect significant.

Errors--that is, when the observer responded with the wrong direction of motion--were analyzed in a corresponding manner to that for motion thresholds. Table 4 shows mean error rates for

the four range configurations. One can see that the two-point flashing range produced almost twice as many errors as the other configurations. A four-way ANOVA showed a significant effect on errors for range configuration, $F(3,36) = 3.44$, $p < .05$. A Newman-Keuls test showed that the two-point flashing range was significantly different from the other three configurations ($p < .05$), which were not significantly different from each other.

The effect of start position was also significant, $F(10,120) = 3.68$, $p < .001$. The error data for all range configurations combined are shown in Figure 9. As with judgment of motion, best performance was near the on-axis position and became increasingly poorer with distance off axis.

Interestingly, direction of relative motion toward or away from the range axis had no effect on error rate in this overall analysis, in contrast to the significant effect it had on judgment of motion. However, the direction of relative motion effect did vary with range configuration, as indicated by their significant interaction, $F(30,360) = 1.68$, $p < .05$. Separate three-way ANOVAs were then computed on errors for each of the range configurations. The only significant effect was direction of relative motion for the path indicator, $F(10,120) = 2.02$, $p < .05$, as indicated in Table 4. Errors toward the range axis were substantially lower for the path indicator than for the other configurations, thus giving rise to the significant DRM x Range Configuration interaction in the previous ANOVA.

<u>Static Simulations</u>

Data from the four observers were combined and probit analyses were conducted on the 2160 trials from both the two-point and extended source range configurations. With chance performance represented by the 50% probability level and certainty represented by 100%, a probability level of 85% correct responses was chosen for the practical purposes of this study. With the two-point range, observers could judge when they were off the range axis by 18.4 arc sec (0.31 arc min). With the extended source configuration, the mean accuracy was 20.2 arc sec (0.34 arc min). The difference between the two range configurations was not significant, $t(3) = 1.35$, $p > .10$. Additional practice and a less conservative criterion probability level would likely have made the performance of these observers approach the 5 to 10 arc sec acuity found by Westheimer and McKee (1977).

Discussion

Observer sensitivity for judging position in the channel depends on the type of range, the starting point in the channel, and the direction of motion. The results have been presented thus far in terms of angular measures of sensitivity. To fully appreciate the magnitudes of the differences it is necessary

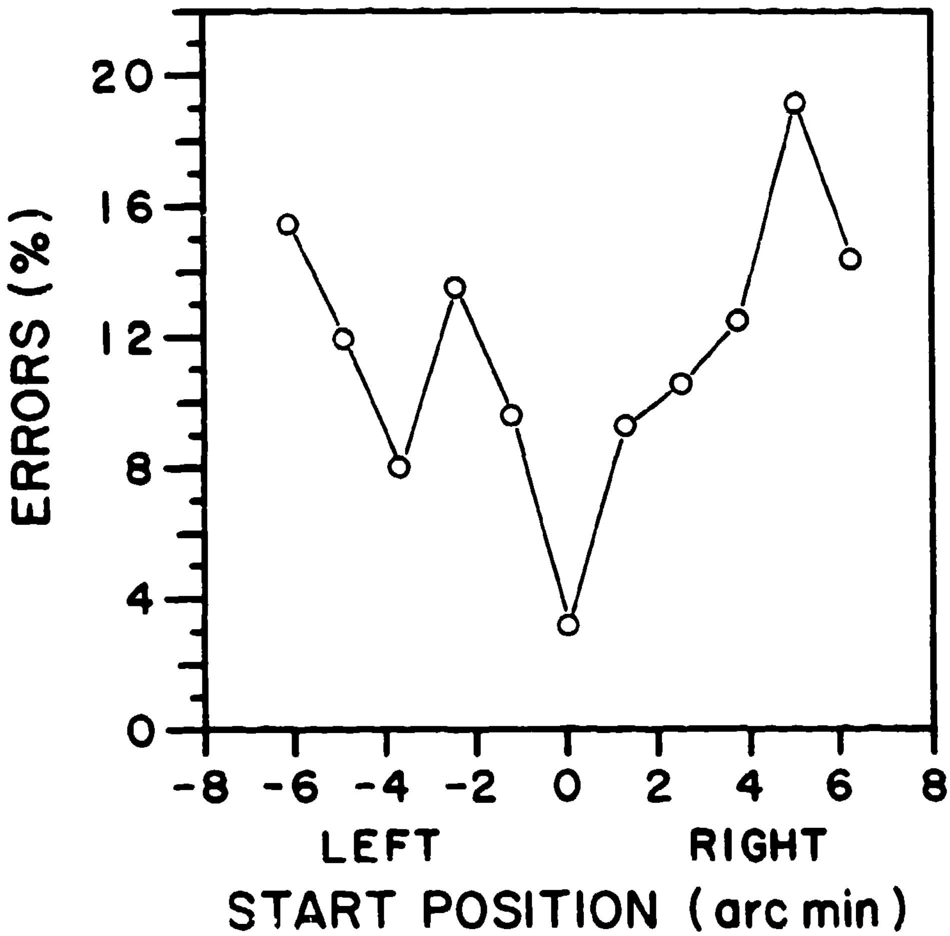

Figure 9. Mean percent errors for four parallax range light configurations combined.

to convert the angular measure to a distance measure. This conversion, however, is dependent on the actual design parameters of the range, in particular the K factor. U.S. Coast Guard design guidelines require that ranges have K factors between 1.5 and 4.5. A range with a K factor less than 1.5 will not change its alignment perceptibly with small changes in lateral position. A range with a K factor greater than 4.5 will change alignment too rapidly with changes in lateral position.

Table 5 shows the deviation of the lower light in arc min for each 3 meter deviation from the range axis for three different channel widths, and the distance in meters that an observer must be from the range axis to see a 0.1 arc min deviation of the lower light. The K factors shown are what may be encountered in transit along a particular channel, as K factor changes with observer distance from the range lights. At the far end of a channel, a range will have a lower K factor than at the near end.

Table 5

Deviation of Range for Several Range Sensitivities

	Channel Widths					
	152 m	229 m	304 m	152 m	229 m	304 m
K Factor	Arc Min / 3 meters			Meters / 0.1 Arc Min		
1.5	0.118	0.079	0.059	2.54	3.81	5.08
2.0	0.133	0.088	0.066	2.26	3.39	4.52
2.5	0.177	0.118	0.089	1.69	2.54	3.39
3.0	0.221	0.148	0.111	1.35	2.03	2.71
3.5	0.266	0.177	0.133	1.12	1.69	2.26
4.0	0.310	0.207	0.155	0.97	1.45	1.94
4.5	0.354	0.236	0.177	0.85	1.27	1.69

Consider now the differences in motion thresholds for the four parallax range configurations of Figure 4. The greater sensitivity of 0.2 arc min for the extended source range, compared to the two-point fixed range, corresponds to a superior alignment accuracy of (2.54 x 2) or 5.08 meters for a 152 meter wide range with a K factor of 1.5. When the K is increased to 4.5 the difference in accuracy is 1.70 meters. Similarly, alignment accuracy for the fixed two-point range is 0.13 arc min or 6.60 meters better than a flashing range when K = 1.5, and 2.20 meters better when K = 4.5, for a 304 meter wide range.

Three of the four parallax ranges showed a threshold difference of 0.4 min arc between judgments on the range axis and judgments at the edge of the channel. This corresponds to a difference in alignment accuracy of 10.2 meters for K = 1.5 and 3.4 meters when K = 4.5 for a 152 m channel width. Depending on channel configuration, such differences could prove substantial.

In comparing the static and dynamic simulation experiments, some caution is advised. It appears that observers' sensitivity to judge position, or whether they are slightly off the range axis, is much greater than sensitivity to detect motion across the range axis. A good deal of this difference may be due to differences in experimental procedure, however. In the static simulations, the observer had to make a rapid right-left alignment judgment of a brief presentation of two lights, thus employing a very sensitive perceptual criterion. In the dynamic simulations, however, the observers had to observe the initial positions of two lights, and then, from memory, determine if the lower light had moved, and in which direction. The tasks involved in the static and dynamic experiments were therefore quite different, and would tend to magnify any real differences in the results.

Since the data for motion thresholds presented above included results from observers who were not experienced in making fine visual discriminations, it is useful to compare the results of the static and dynamic experiments for just the four psychophysically experienced observers who participated in the static experiments.

Table 6

Position and Motion Thresholds for Four Parallax Range Configurations by Groups of Observers (arc min)

Range Configuration	Position Threshold (Static): Four Experienced Observers	Motion Threshold (Dynamic): Four Experienced Observers	Five Inexperienced Observers	All Observers
Two-point Fixed				
On-axis	0.31	0.77	2.09	1.40
Mean		1.21	2.12	1.64
Two-point Flashing				
On-axis		1.24	1.94	1.53
Mean		1.46	2.00	1.76
Extended Source				
On-axis	0.34	0.68	2.02	1.27
Mean		0.86	2.05	1.44
Path Indicator				
On-axis		0.89	1.92	1.45
Mean		1.01	1.90	1.50

Table 6 shows position thresholds and motion thresholds for the on-axis start positions by range configuration for three groups, the four experienced observers who served in both the

static and dynamic experiments, the five inexperienced observers, and all 13 observers. Also shown are the mean motion thresholds over all start positions for each configuration. The position thresholds are most meaningfully compared to motion thresholds at the on-axis, or zero deviation, start position (Figures 4 - 8), as measurements for both situations were made about this point.

Several points may be seen in Table 6. For the same four observers, sensitivity to position around the range axis is substantially better than sensitivity to motion, for both the two-point and the extended configurations. This, of course, simply means that it is much easier for the navigator to tell if he is on or slightly off the range axis than to discern whether he is moving slowly toward or away from the axis. It is difficult to assess just how much better sensitivity to position is, however, because of the methodological differences involving task criteria mentioned above.

Secondly, the experienced observers performed much better than the group of five inexperienced observers, and therefore better than the entire group of 13 observers. The group of four experienced observers had thresholds averaging 1.1 arc min more sensitive than the inexperienced group and 0.5 arc min more sensitive than all observers combined. Examination of the data from the experienced group for the four range configurations showed the same results as in Figure 4, but with the curves shifted in the direction of greater sensitivity. This indicates that with greater experience, performance in using range light information improves substantially, for all configurations, to about the same extent. This improvement in accuracy corresponds to 12.7 meters for K = 1.5 and 4.25 meters when K = 4.5 between the experienced group and all observers at a 152 m channel width.

Finally, sensitivity to motion, especially for experienced observers, is better around the range axis than away from it. This is shown by the consistent differences between the on-axis threshold and the mean threshold of all start positions, for each range configuration. It is interesting to note that for the inexperienced group, the on-axis threshold is virtually the same as the mean of all start positions. This seems to indicate that much of improvement at this task occurs around the on-axis position, and that motion perception remains difficult near the edge of the channel.

The question might be raised that the inexperienced observers were using a more stringent criterion by which to make their judgments of motion, that is, their higher threshold sensitivities may have been the result of waiting longer to make sure in what direction the range indication had moved. This strategy would then produce a lower error rate than for other observers, as well as an apparent decrease in sensitivity. Examination of error percentages of the five inexperienced observers, however, showed

their mean error rate to be 14.8%, higher than the 11.6% for all observers combined as shown in Table 4. We may therefore conclude that greater experience produces improved sensitivity and reduced error rates, rather than a shift in judgment criterion.

Summary

This study has shown that the current two-point fixed (always on) navigation range light configuration affords a high degree of sensitivity in determining lateral position and direction of motion relative to the range axis. With two-point flashing range lights, sensitivity is slightly decreased and errors in judging direction of motion are significantly higher than with the fixed lights. Two alternative parallax range light configurations afforded a slight potential improvement in sensitivity over the two-point fixed lights.

A group of experienced observers performed substantially better than the entire group, which included many inexperienced observers. There is evidence that with training or experience, performance can be improved regardless of range light configuration.

The differences in sensitivity between motion judgments toward and away from the range axis are significant and likely to impact the use of parallax ranges. Mariners are less sensitive to motion when heading toward the channel edge. This seems almost the opposite of what a range indicator should be capable of displaying. If a vessel is approaching the channel edge, mariners should be acutely aware of this. Perhaps single-station range configurations will be found that yield better performance for motion toward the channel edge.

These findings, then, describe the sensitivity afforded by present range light configurations and will serve as a baseline to allow comparison of proposed single-station range lights to evaluate their adequacy as aids to navigation. Studies of three single-station range lights proposed by the U.S. Coast Guard are in progress. These findings will be reported in subsequent presentations (Mandler, Laxar, and Luria, 1990) and NSMRL reports.

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